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Production systems, land cover change and soil factors affecting pasture production in semi-arid Nakasongola

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Abstract

The current pace of rangeland degradation imparted by appalling land use and management systems is greatly limiting the potential of the soil resource to support pasture production in semi-arid rangelands of Uganda. Our objectives were to determine the effects of land cover change and production systems on pasture biomass yield and to identify the critical soil factors affecting pasture production in Nakasongola. The area was stratified into three production systems and three land cover types from which six pasture and soil samples were collected following a Modified-Whittaker sampling method. Pasture biomass was significantly high ($p < 0.0001$) under herbaceous cover (2019 kg/ha) compared to woody (1302 kg/ha) and bare which had no pasture biomass. The settled production system had a significantly ($p = 0.013$) high pasture biomass (1266 kg/ha) compared to non settled (1102 kg/ha) and semi settled systems (953 kg/ha). Biomass yield was more associated with high levels of organic matter ($r = 0.91$), calcium ($r = 0.91$), magnesium (0.83), nitrogen ($r = 0.77$) and base saturation ($r = 0.88$). It can be concluded that maintaining native vegetation cover of the rangelands and increasing levels of limiting nutrients are the major strategies for increasing pasture production in semi-arid rangelands of Nakasongola.

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Introduction

Rangelands are generally known to be overgrazed throughout the world and their potential to produce edible forage for livestock feeding has greatly declined (Wilson and Macleod, 1991). The most important product provided by rangelands is the rich diversity of forages, most especially the herbaceous vegetation that is extensively grazed by animals. However, the increasing population pressure imposes a great threat to sustainability of natural vegetation through settlements and increased cultivation in grasslands which reduces the area available for grazing (Kristjanson et al., 2002). The transformation of land cover and land use system in pastoral rangeland communities is believed to have significant impacts on the productivity of the herbaceous layer which needs detailed understanding if sustainable rangeland management practices are to be developed. Of the three major drivers of vegetation structure and composition in rangeland ecosystems; fire, herbivory and climate (Noy-Meir, 1993; Van Auken and Bush, 1997; Archer *et al.*, 1995; Higgins *et al.*, 2000; Roques *et al.*, 2001; Briggs *et al.*, 2002; Hudak and Wessman, 2001; Lechmere-Oertel, 2003; Azardi et al., 2009), the impact of herbivory has been implicated by many authors as a critical force in semi-arid rangelands (Archer, 1994; Brown and Archer, 1999; Van Auken, 2000; Higgins *et al.*, 2000; Jeltsch *et al.*, 2000). As such, many traditional rangeland management practices were considered unsustainable and hence the proposition to devise 'better' rangeland management practices. However, the alienation of traditional practices in most parts of the world was done with limited scientific evidence and is thus also believed to have contributed to accelerated land cover changes in the rangelands (Briske et al., 2008). Increased loss of vegetation cover, soil erosion, loss of organic matter and essential soil nutrients are among the consequences of changes in land use and cover types in the semi-arid rangeland ecosystem with major striking effects being the decline in herbaceous vegetation upon which pastoral livelihoods are anchored.

Decline in pasture production is of global concern to all rangeland managers. Woody encroachment, creation of bare patches of soil and cultivation are major factors deterring the available land for grazing, reduces the quantity and quality of primary production. Keeping large livestock numbers, in a bid to increase profits in privately owned lands or increase resource use in communally owned lands (the tragedy of the commons) and the expansion of cultivation in grazing areas are major drivers of reduced herbaceous cover and production in the rangelands of Uganda. With increased stock density, the soils become compacted, infiltration reduces and runoff increases leading to loss of major soil nutrients and organic matter. This reduces the growth potential of pastures (shallow feeders) but deep rooted woody species continue to survive leading to an increase in woody cover at the expense of grasses.

Rangeland management for sustainable production is not a new phenomenon. Traditionally, pastoralists used to reserve dry season grazing areas and only grazed livestock in such common pool resource areas when an intense drought strikes. Elsewhere, animals could graze the rangeland continuously to levels perceived to be recuperative and moved to other places for grazing. However, the breakdown of traditional rangeland management practices, changes in land ownership and the lifestyles of pastoralists through individualization of land and sedentarization of pastoralists, the influx of people with a different way of life from high potential areas (cultivators) led to the collapse of the ecological and production sustainability of Uganda's rangeland systems. Different production systems (land use) are now practiced in the rangelands of Uganda which include the permanently settled systems that practice rotational grazing (individualized and sedentarization), semi-settled systems where continuous grazing is practiced (there is regulation of stock numbers and involves movement to better places in dry seasons) and the non-settled systems where many people own small herds which graze everywhere. These three land use practices subject the rangeland to grazing intensities that lead to overgrazing and degradation resulting into ecosystems that can no longer maintain their stability, function and structure due to subsequent changes in land cover.

The system of production applied on a land resource affects the ecosystem, vegetation cover, soil and socio-economic factors of the communities inhabiting a given area. Appropriate rangeland use systems that involves resting of land rehabilitates degraded areas, increases biodiversity in favor of desirable plant species, increases vegetation cover over land through colonization of formerly bare patches and has significant influence on the soil component through reduced runoff, increased infiltration and increased organic matter and soil nutrients (Mureithi, 2006; Mureithi et al., 2010; Ekaya and Kinyamario, 2003). However, the ability of resting to rehabilitate depends on whether the ecosystem was not severely degraded past their recuperative capacity. Otherwise, severely degraded rangelands may fail to return to their original states when rested (Westoby et al., 1989; O'Connor, 1991; Kironchi, 1998) or may be converted to an entirely different state (Kosmas et al., 2000).

More so, because of the low input production systems practiced with constraints in soil fertility improvement, the issue of increasing soil fertility for increased pasture production is more of a blanket statement with no major emphasis on critical nutrients affecting pasture production. The objective of this study was to assess the effect of land cover change and production system on pasture production and to identify the most critical soil nutrients limiting pasture production in semi-arid rangelands of Nakasongola district, Uganda.

Materials and methods

The study was conducted in Nakasongola district of Uganda, in two subcounties of Nabiswera and Nakitoma. Nakasongola district covers an area of 4,909 km^2 and is located between 0^o 57' 44.89" to 1^o 40' 42.76" North latitude and between 31^o 58' 03.77" and 32^o 48' 00.29" East longitude. The area receives a bi-modal rainfall regime with the first rainy season occurring in the months of March–May while the second in September-November. The mean annual rainfall ranges between 500 mm and 1600 mm with seasonal variations and prolonged droughts at an interval of 8 – 12 years. The mean daily minimum temperature ranges between 15.0^{o}C and 20.9^{o}C while the mean daily maximum temperature ranges between 25.4^{o}C and 33.7^{o}C. Average humidity ranges from 80% in the morning to 56% in the afternoon. The potential evapotranspiration remains high through the year (~130 mm/month and ~1586 mm/annum) and shows less variability unlike the rainfall.

Vegetation and land use

The dominant vegetation type in Nakasongola in the early 1960's was dry savanna vegetation with Hyparrhenia filipendula and Loudentia arundinacea as the dominant grasses and scattered but numerous fire-tolerant species of trees and shrubs commonly by *Combretum terminalis* and *Acacia brevispica* (Radwanski, 1960; Langdale-Brown *et al.*, 1964). The associated grass-shrub savanna was relatively sparse with a lot of uncovered ground. This together with termite activity was the main cause of low organic matter in the topsoil of the Buruli series. There was generally very little settled agriculture on Buruli soils which were used mainly for extensive grazing by relatively numerous herds of cattle. Nakasongola district is classified under the banana-millet-cotton farming system. Because of the less stable rainfall, there is a great reliance on annual food crops basically millet, sorghum, groundnuts, cassava, pigeon peas and maize, with cotton as a major cash crop and livestock production dominating in the drier areas of the district (Kirumira, 2008). For many years, the Nakasongola rangelands were predominantly used for livestock production (cattle, goat and sheep), under the communal grazing systems and this had little effect on the natural vegetation (Kisamba-Mugerwa, 2001). However, in recent decades, the rangelands have been severely encroached by cultivators from high potential areas driving major land use changes. Charcoal burning is also another "un-necessary" economic activity on which a good number of people hinge their livelihood in Nakasongola district.

Soils

Earlier studies on the soils and land use in Uganda classified the soils of Nakasongola under the Buruli catena (Radwanski, 1960). This catena represented the driest part of Buganda province. The clay content in the upper layer was 12%, the nutrient status of this catena was very inferior in all respects with lower organic carbon (1%) in the upper horizon, pH of below 5 and deficient in available phosphorus and all the major exchangeable bases. The soil lacks structure and has a tendency to set hard on drying. The analysis of soil samples from Buruli catena in 1960 for selected physical and chemical properties between 5 – 20 cm depth showed the following ranges; Silt (2 – 6%), clay (12 – 20%), Ca (0.4 – 0.7), Mg (0.3 – 0.6), K (0.08 – 0.19), Na (0.0), Mn (0.05 – 0.22), Total exchangeable cations (0.24 – 1.52), CEC (3.7 – 4.7), pH (4.1 – 4.7), OC (0.56 – 0.96) and P_2O_5 (10 – 14) (Radwanski, 1960).

Soil sampling and analysis

The study area was characterized into three rangeland management systems (settled, semi-settled and non-settled) which were stratified into three land cover types (bare, herbaceous and woody) in which six locations were randomly selected for establishment of the sampling sites. A Modified-Whittaker plot (20 m × 50 m) was placed with the long axis parallel to the environmental gradient (Stohlgren *et al.*, 1995). In each plot of 1000 m² was nested subplots of three different sizes. A 5 m × 20 m (100 m²) subplot in the center, two 2 m × 5 m (10 m²) subplots in opposite corners and ten 0.5 m × 2 m (1 m²) subplots (six arranged systematically inside and adjacent to the 1000 m² plot perimeter and four arranged systematically outside and adjacent to the 100 m² subplot perimeter). Five soil samples were taken from each of the four corners and center of each Modified-Whittaker plot using cores of 5 cm diameter. Due to the presence of rocks in some areas, it was hard to maintain a consistent core depth and thus core depths were varied between 8 cm and 15 cm. The five samples obtained were then pooled into a basin, mixed thoroughly to form one composite sample that was packed in a labeled plastic bag for laboratory analysis. Near the sites where soil cores were obtained, an undisturbed block of soil was also dug and taken for determination of soil structure and bulk density. The soil samples were air-dried for 48 hours, sieved with a 2 mm sieve, oven-dried at 60°C for 24 hours and then used for analysis of selected chemical and physical properties. Soil particle size distribution was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986) while soil aggregate stability was determined by the wet sieving technique (Kemper and Rosenau, 1986) and bulk density by the gravimetric method (Blake and Hartge, 1986). Soil pH was measured using a pH meter in a 1:2 soil: water ratio (Schofield and Taylor, 1955), nitrogen by the Kjeldahl procedure (ISSCAS, 1978), total P by the perchloric acid digestion method (Mehta *et al.*, 1954) and soil organic carbon was determined using the modified Walkley-Black method (Mebius, 1960).

Pasture sampling

Pasture sampling was done towards the end of the rain reason when most of the plants were at the peak of their phenology and when there are optimum biomass production. All pastures present in each of the 1 m² and 10 m² subplots were cut at ground level using a sickle and 1 m² at the center of the 100 m² subplot. The collected pastures from all sampling points within one Modified-Whittaker plot were then pooled, packed in labeled bags, weighed and recorded. The fresh forage was air dried and then oven dried at 80° C for 48 hours and finally re-weighed (Roberts et al., 1993).

Data treatment

Analysis of variance was conducted using XLSTAT, 2010 package to analyze the difference in biomass yield as affected by production system, land cover type and the interaction between production system and land cover type. The hypothesis tested was that there are no significant differences in pasture biomass yield among production systems and land cover types. Type III sum of squares were used to identify significance levels and mean pasture biomass yield was separated using LS means. 15 selected physical and chemical soil properties (pH, OC, OM, N, Ca, C:N, Mg, K, Na, CEC, Ks, bulk density, P, base saturation and porosity) were subjected to Principle Component Analysis in order to analyze the correlations between biomass production and soil properties and to identify the most critical soil properties/nutrients limiting biomass yield. Squared Cosines values of variables (soil properties) were used to identify the factors that are more linked with most variables.

Results

Effect of land cover change on pasture biomass yield

Pasture biomass yield ranged between zero and 3116 kg/ha, with a mean of 1107±925.6 kg/ha. Highest biomass yield was under herbaceous cover (2019 kg/ha) followed by woody (1302 kg/ha) and least (none) in bare cover (Fig. 1). The settled production system had more biomass yield (1266 kg/ha) followed by the non-settled (1102 kg/ha) and least in semi-settled (953 kg/ha) (Fig. 2).

Pasture biomass yield was significantly different ($p < 0.0001$) across land cover types (Table 1) and significantly different ($p = 0.013$) between settled and semi-settled production systems (Table 2). The interaction between production systems and cover types showed significant differences between different combinations (Table 3). High pasture biomass was recorded under herbaceous vegetation in settled systems while no biomass was recorded in all production systems where bare ground existed.

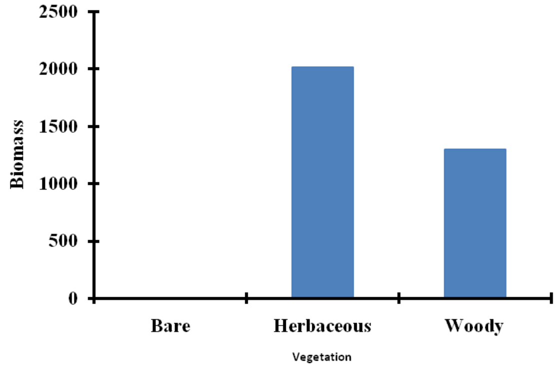

Fig. 1. Pasture biomass yield under different land cover types.

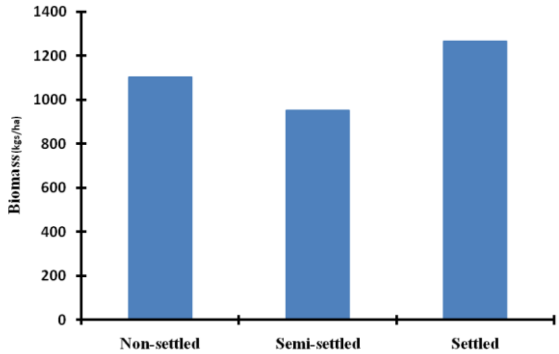

Fig. 2. Pasture biomass yield under different production systems.

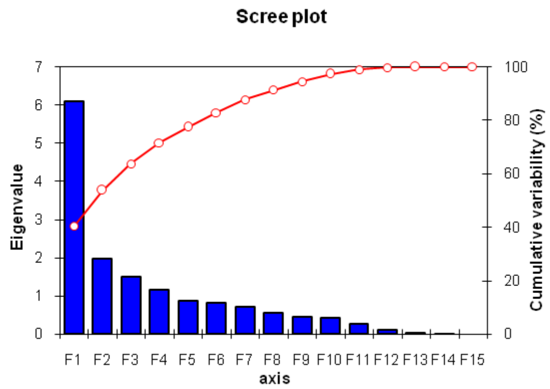

Fig. 3. Eigenvalues and cumulative variability explained by the fifteen factors.

Identifying critical soil properties affecting pasture biomass yield

Fifteen factors were obtained with the first five factors explaining 77.4% of the total variability (Figure 3) and having the highest cosines values for each variable (Table 4). The first two eigenvalues correspond to a high percentage of the variance (54%) and are thus a good quality projection of the initial multi-dimensional table. Since there are 15 factors out of the 15 variables uploaded for analysis, none of the soil properties used in this study had a strong negative correlation (r = -1) with others. However, available phosphorus is negatively correlated with all variables except CEC, Ks and porosity.

Table 1. Fishers LSD analysis of differences between land cover types at 95% confidence interval.

Contrast	Difference	Pr > Diff
Herbaceous vs Bare	2019.222	< 0.0001
Herbaceous vs Woody	717.417	< 0.0001
Woody vs Bare	1301.806	< 0.0001

Factor 1 and factor 2 had the highest cosines values for most variables compared to other factors with factor 1 having eight variables (pH, OC, OM, N, C:N, Ca, Mg and base saturation) while factor 2 having three variables (Ks, P and Porosity). Therefore, the trends in biomass production can be best viewed on factor 1 and factor 2 maps. The correlation circle based on factor 1 and 2 (Figure 4) show that Factor 1 is correlated with pH (r = 0.64), OC (r = 0.907), OM (r = 0.907), N (r = 0.768), C:N (r = 0.574), Ca (r = 0.905), Mg (r = 0.828), CEC (r = 0.601) and Base saturation (r = 0.878) while Ks (r = 0.771), P (r = 0.698) and porosity (r = 0.6) are correlated with F2. However BD, Na and K are very close to the center which shows that their variability is more explained by other factors than F1 and F2. Analysis of correlation of variables with factors (Table 5) shows that BD is more correlated to factor 4 (r = 0.734 while Na (r = 0.679) is highly correlated to factor 3 and K can be more explained on F1 and F3 axes where its correlation with both factors is similar (r = 0.407).

Table 2. Fishers LSD analysis of differences between production systems at 95% confidence interval.

Contrast	Difference	Pr > Diff
Settled vs Semi-settled	313.028	0.013
Settled vs Non-settled	163.778	0.184
Non-settled vs Semi-settled	149.25	0.226

Table 3. LS means used to differentiate the interactions between production systems and land cover types.

Production system*land cover type	Pasture Biomass (kg/ha)
Settled*Herbaceous	2320[a]
Settled*Woody	1478[bc]
Settled*Bare	0.000[d]
Semi-settled*Herbaceous	1643[b]
Semi-settled*Woody	1216[c]
Semi-settled*Bare	0.000[d]
Non-settled*Herbaceous	2095[a]
Non-settled*Woody	1211[c]
Non-settled*Bare	0.000[d]

Means followed by the different superscripts are significantly different at the 0.05 probability level.

High pasture biomass is more associated with high levels of OM, Ca, Mg, N and Base saturation than other variables (Fig. 4a & b), while decline in these soil properties is associated with reduction in pasture biomass yield. Substitution of pasture biomass yield with land use/cover types on the observations plot on F1 and F2 axes show that points with high pasture biomass yield correspond with herbaceous vegetation type while those with least pasture biomass yield correspond to bare ground (Fig. 5a & b)

Table 4. Squared cosines of the variables.

Variable	Factors				
	F1	F2	F3	F4	F5
pH	0.413	0.111	0.013	0.036	0.007
OC (%)	0.823	0.028	0.018	0.032	0.002
OM (%)	0.823	0.028	0.018	0.032	0.002
N (%)	0.589	0.023	0.156	0.016	0.005

C:N	0.330	0.187	0.099	0.130	0.002
Ca (me/100g)	0.818	0.001	0.091	0.012	0.002
Mg (me/100g)	0.685	0.001	0.135	0.025	0.005
K (me/100g)	0.165	0.100	0.165	0.239	0.007
Na (me/100g)	0.048	0.020	0.462	0.033	0.152
CEC (me/100g)	0.361	0.028	0.022	0.002	0.421
Ks (m/s)	0.095	0.595	0.001	0.025	0.005
BD (g/cm3)	0.000	0.006	0.113	0.538	0.039
P (ppm)	0.054	0.488	0.023	0.014	0.085
BS (%)	0.770	0.000	0.072	0.031	0.019
Porosity	0.111	0.360	0.127	0.001	0.121

BS – Base saturation.The greater the squared cosine, the greater the link with the factor. Bold figures represent the highest squared cosines for each variabl.

Discussion

Effect of land use and cover change on pasture biomass yield

The wide variation in mean biomass yield shows that great differences exist in pasture production across production systems and vegetation types. The high biomass yield in herbaceous cover was because of limited degradation, high nutrients levels and maximum production due to limited competition for resources with woody species. Because most of the woody vegetation is covering formerly degraded grasslands with remnants of bare ground under the woody canopy, there is limited pasture growth, under woody cover. Also, the increased competition between herbaceous and woody species for nutrients, water and light hinders pasture growth under the woody canopy. Because the settled production system allows ample time for pastures to regenerate after grazing, there is high biomass yield compared to non-settled and semi-settled systems where continuous grazing is practiced with limited resting of land to enable regeneration of pastures. These findings are supported by earlier studies (Biamah, 1986; Kironchi, 1998) who noted that semi-arid rangelands are resilient ecosystems that are capable of regenerating once the drivers of degradation are lifted before the recuperative capacity is surpassed. Therefore, since woody and bare lands are former grasslands that were so much degraded by overstocking, their ability to support pasture production is still low as land was subjected to extensive soil erosion and runoff which depleted most of the organic matter and soil nutrients as reported by Verity and Anderson (1990). Similar results have been reported elsewhere with areas under restricted grazing having high biomass yield compared to freely accessed grazing areas (Makokha et al., 1999; Cleemput et al., 2004; Mureithi et al., 2010).

Table 5. Correlations between variables and factors.

Variable	Factors				
	F1	F2	F3	F4	F5
pH	0.643	0.333	0.112	0.191	-0.086
OC (%)	0.907	-0.168	0.134	0.179	-0.043
OM (%)	0.907	-0.168	0.134	0.179	-0.043
N (%)	0.768	0.152	0.395	-0.125	-0.070
C:N	0.574	-0.432	-0.315	0.361	-0.042
Ca (me/100g)	0.905	0.038	-0.302	-0.109	0.040
Mg (me/100g)	0.828	-0.031	-0.367	-0.159	0.068
K (me/100g)	**0.407**	-0.316	**0.407**	-0.488	-0.083
Na (me/100g)	0.220	-0.142	**0.679**	-0.181	0.390
CEC (me/100g)	0.601	0.166	-0.147	-0.048	0.649
Ks (m/s)	0.308	0.771	-0.028	0.157	-0.068
BD (g/cm3)	0.010	-0.076	0.336	**0.734**	0.198
P (ppm)	-0.231	0.698	-0.152	-0.119	0.292
BS (%)	0.878	-0.001	-0.269	-0.176	-0.138
Porosity	0.334	0.600	0.357	0.028	-0.347

BS – Base saturation. Bold text shows high correlation between variables and corresponding factors.

The relatively low observed pasture biomass yield under all production systems (maximum of 3000 kg/ha) compared to that earlier reported in the central rangelands of Uganda of 4000 – 5000 kg/ha (Harrington, 1974) is attributed to the fact that regardless of the production system, the available grazing lands have a high stocking density which increases the grazing intensity and limits pasture growth. Bartolome (1993), Derner and Hart (2007) and Schuman et al. (2009) also reported similar results where they observed that heavy grazing intensities had detrimental impacts on pasture production. It was also noted that specialized grazing systems aimed at controlling selective grazing work poorly in semi-arid rangelands compared to simpler grazing methods based on controlling grazing intensity (Bartolome, 1993). This explains why non-settled systems with light grazing intensity have high biomass yield compared to semi-settled systems with high grazing intensities.

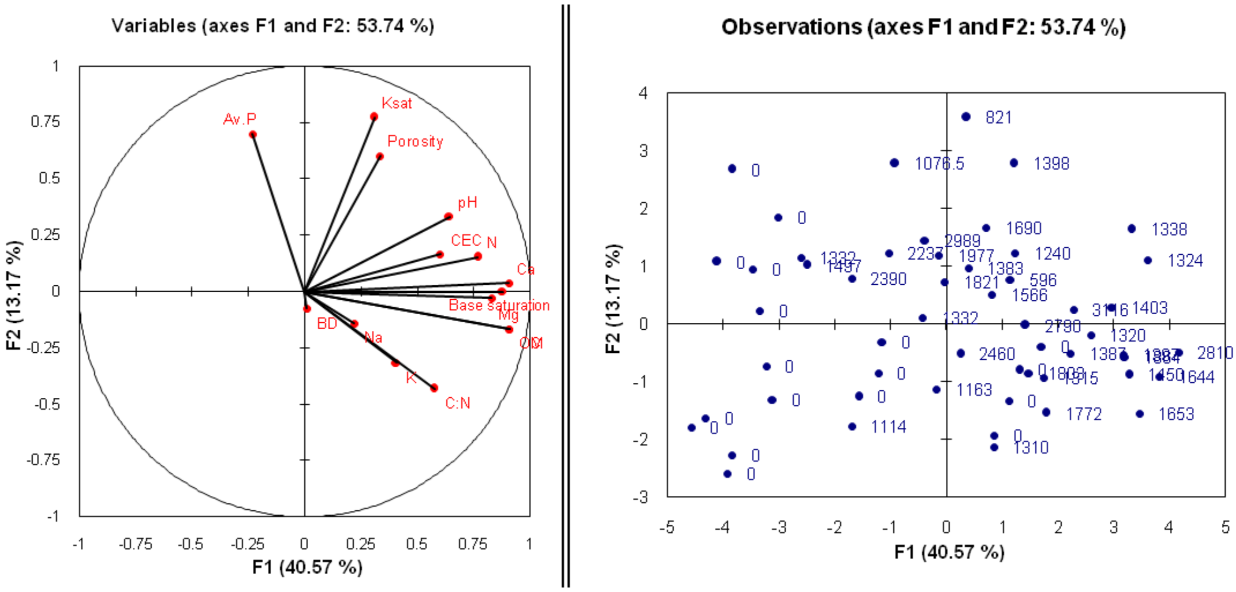

Fig. 4. Correlation of variables with factors 1 and 2 (4a) and Ordination biplot of soil properties and biomass yield on factor 1 (Horizontal axis) and factor 2 (Vertical axis) which explain 40.57% and 13.17% of the variation respectively (4b).

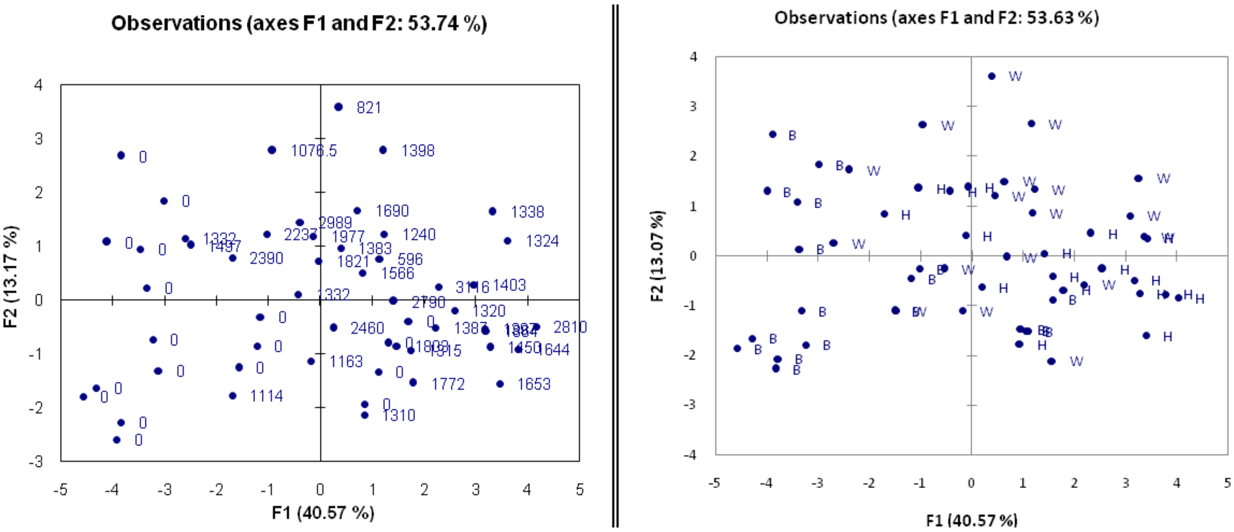

Fig. 5. Observations of pasture biomass (5 a) and land use/cover types (5 b) on F1 and F2 axes. B = Bare, H = Herbaceous, W = Woody.

Identifying critical soil properties affecting pasture biomass yield

Because of the high temperatures associated with the semi-arid rangelands, the rate of primary net production and decomposition are low. Because of this, organic matter and nitrogen are generally limiting nutrients in the rangeland ecosystem of Nakasongola and are thus among the most critical nutrients affecting pasture biomass yield. Because organic matter influences most soil properties and nutrient availability, the low organic matter fraction translates into lower pH levels and CEC which in turn limits pasture production. Since most of the exchangeable bases that could counteract low pH are extensively lost due to excessive erosion, Ca and Mg become important nutrients required for increased pasture production. The results of this study are supported by the findings of Mugerwa et al. (2008) who noted that application of cattle manure on degraded rangelands significantly increased pasture biomass yield. Organic matter has also been identified as a major factor limiting crop and pasture production in many other ecosystems across the globe and increase in organic matter leads to an improvement in many other physical and chemical properties of soil.

Conclusion

The encroachment of grasslands by bare and woody vegetation has led to a decline in pasture biomass yield and therefore has strong implications on the sustainability of pastoral livelihoods in the semi-arid rangelands of Nakasongola. The low pasture biomass yield in woody understorey implies that most native pasture species in the rangelands of Nakasongola are not shade tolerant and therefore increased woody encroachment will most likely wipe out indigenous nutritive pastures in the rangeland. Organic matter, nitrogen, calcium and magnesium are the most critical nutrients limiting pasture biomass yield. Rangeland management strategies for improving soil quality and pasture production should therefore be strongly focused at increasing the levels of these nutrients.

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